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ELECTRICALLY STABILIZED SURFACE-DIRECTOR ALIGNMENT LAYER

Technical field

The present invention generally relates to the field of liquid crystals. More specifically, the present invention relates to a liquid crystal device including an electrically stabilized surface-director alignment layer.

The invention also relates to a method for manufacturing a liquid crystal device and a method of controlling a liquid crystal bulk layer.

Technical background

Liquid crystals, widely used at present as electro-optical media in display devices, are organic materials with anisotropic physical properties. Liquid crystals are made of long rod-like molecules which have the ability to align along their long axis in a certain direction (orientation). The average direction of the molecules is specified by a vector quantity and is called director.

The operation of the liquid crystal displays is based on the changes of the optical characteristics, such as light transparency, light absorption at different wavelengths, light scattering, birefringence, optical activity, circular dichroism, etc, of the liquid crystal in the display caused by an applied electric field (direct coupling).

One of the basic operational principle of liquid crystal displays and devices is the switching of the orientation of the liquid crystal molecules by an applied electric field that couples to the dielectric anisotropy of the liquid crystal (dielectric coupling). Such a coupling gives rise to an electro-optic response quadratic with the applied electric field, i.e. independent of the field polarity.

There exist a number of different types of LCDs whose operation is based on dielectric coupling, espe-

cially dynamic scattering displays, displays using deformation of homeotropically aligned nematic liquid crystal, Schadt-Helfrich twisted nematic (TN) displays, super twisted nematic (STN) displays, in-plane switching (IPS) nematic displays, etc.

For modern applications, a LCD should possess several important characteristics, such as a high contrast and brightness, a low power consumption, a low working voltage, short rise (switching) and decay (relaxation) times, a low viewing angle dependence of the contrast, a grey scale or bistability, etc. The LCD should be cheap, easy to produce and to work with. None of the prior-art LCDs is optimised concerning all the important characteristics.

Nematics are the simplest structure of the liquid crystals which is formed when the liquid crystal molecules align themselves toward a particular direction in space.

In most of the conventional nematic liquid crystal displays, operating on the basis of the dielectric coupling, the electric field is applied normally to the liquid crystal bulk layer and the liquid crystal bulk molecules are switched by the electric field in a plane perpendicular to the confining substrate surfaces (so-called out-of-plane switching). These displays are usually slow, and nearly all suffer from non-satisfactory angular dependence of the contrast.

It may be noted that there is also another type of LCDs with in-plane switching, in which the electric field is applied parallel to the liquid crystal bulk layer and the liquid crystal bulk molecules are switched in a plane parallel to the confining substrate surfaces. These displays exhibit a very small angular dependence of the image contrast but the resolution and the switching times are not satisfactory.

In the displays discussed above, the desired initial alignment of the liquid crystal layer is achieved by ap-

propriate surface treatment of the confining solid substrate surfaces. In the absence of external fields, the initial liquid crystal alignment is defined by solid surface/liquid crystal interactions. The orientation of the liquid crystal molecules adjacent the confining surface is transferred to the liquid crystal molecules in the bulk via elastic forces, thus imposing essentially the same alignment to all liquid crystal bulk molecules.

The director of the liquid crystal molecules near the confining substrate surface(s) (herein also called surface director) is constrained to point in a certain direction, such as perpendicular (also referred to as homeotropic or vertical) or parallel (also referred to as homogeneous or planar) to the confining substrate surface. The type of alignment in liquid crystal displays operating on the coupling between liquid crystal dielectric anisotropy and applied electric field is chosen in accordance with the sign of the dielectric anisotropy.

In liquid crystal cells employing a liquid crystal bulk having a negative dielectric anisotropy, it is important to uniformly orient the director of the liquid crystal bulk molecules vertically to the substrate surfaces. An example of a method for establishing a homeotropic alignment comprises coating the confining substrate surfaces with a surfactant, such as lecithin or hexadecyltrimethyl ammonium bromide. The coated substrate surfaces is then also preferably rubbed in a predetermined direction, so that the field-induced planar alignment of the liquid crystal molecules will be oriented in the rubbing direction.

In liquid crystal cells employing a liquid crystal bulk having a positive dielectric anisotropy, it is important to uniformly orient the director of the liquid crystal bulk molecules in parallel with the substrate surfaces. For twisted nematic liquid crystal cells, it is also important to orient the liquid crystal bulk molecules at a certain inclined orientation angle (tilt an-

gle) to the substrate. Known methods for establishing homogeneous alignment is, for instance, the inorganic film vapour deposition method and the organic film rubbing method.

In the inorganic film vapour deposition method, an inorganic film is formed on a substrate surface by vapour-depositing an inorganic substance, such as silicon oxide, obliquely to the confining substrate so that the liquid crystal molecules are oriented by the inorganic film in a certain direction depending on the inorganic material and evaporation conditions. Since operation efficiency is low, this method is practically not used.

According to the organic film rubbing method, an organic coating of, for instance, polyvinyl alcohol, polyoxyethylene, polyamide or polyimide, is formed on a substrate surface, the coating is then baked, generally at 200-300°C, and the surface is thereafter rubbed in a predetermined direction using a cloth of e.g. cotton, nylon or polyester, so that the liquid crystal molecules will be oriented in the rubbing direction. Polyimide is most often used due to desired chemical stability, thermal stability, etc.

In all of the above disclosed methods of aligning the director of the liquid crystal bulk molecules near the confining substrate(s), a so-called surface-director alignment layer is applied on the confining substrate surface(s) facing said liquid crystal bulk.

In the prior of art, there are in principal three different techniques for changing the optical performance of liquid crystals by accomplishing a new molecular orientation of the liquid crystals that differs from the initial alignment.

The first, most widely used technique for reorientating the molecules is to apply an external electrical field over the entire bulk liquid crystal layer. Due to direct coupling between the electric field and some of the liquid crystal material parameters, such as dielec-

tric anisotropy, the field will directly reorient the liquid crystal bulk molecules in a new direction if their initial alignment does not correspond to a minimum energy of interaction of the electric field with some of the liquid crystal material parameters.

The second known technique for reorienting the molecules of a liquid crystal layer is to design one or both of the confining alignment surfaces as a photo-controlled "command surface". Such a photo-controlled command surface is capable, when subjected to, for instance, UV light, to change the direction of alignment imposed by the surface on the liquid crystal molecules in contact with the surface. The concept of "photo commanded surface" has been described by K. Ichimura in a number of papers overviewed in Chemical Reviews, 100, p.1847 (2000). More specifically, an azobenzene monolayer is deposited onto the inner substrate surface of a sandwich cell containing a nematic liquid crystal layer. The azobenzene molecules change their conformation from "*trans*" to "*cis*" under illumination with UV light. The azobenzene molecules are anchored laterally to the substrate surface by the aid of triethoxysilyl groups. The *trans*-isomer of azobenzene moieties imposes a homeotropic alignment of the nematic liquid crystal, whereas the *cis*-isomer gives a planar orientation of the liquid crystal molecules. Hence, the conformational changes of the molecules in the alignment layer caused by the UV illumination will result in a change of the alignment of the nematic liquid crystal molecules. The relaxation to the initial alignment is obtained by illuminating the sample with VIS-light or simply by heating it to the isotropic state.

The third known principle for reorientating liquid crystal molecules involves the use of so-called Electrically Commanded Surfaces (ECS). This principle is described in the published International patent application No. WO 00/03288. The ECS principle is used to primarily

control a ferroelectric liquid crystalline polymer layer. According to ECS principle, a separate thin ferroelectric liquid crystalline polymer layer is deposited on the inner surfaces of the substrates confining a liquid crystal bulk material in a conventional sandwich cell. The ferroelectric liquid crystalline polymer layer acts as a dynamic surface alignment layer imposing a planar or substantially planar alignment on the adjacent liquid crystal bulk material. More specifically, when applying an external electric field across the cell - and thereby across the surface alignment layer - the molecules in the separate ferroelectric liquid crystalline polymer layer will switch. This molecular switching in the separate polymeric layer will, in its turn, be transmitted into the bulk volume via elastic forces at the boundary between the separate alignment layer and the bulk layer, thus resulting in a relatively fast in-plane switching of the bulk volume molecules. The ECS layer should be very thin (100-200 nm), and should preferably be oriented in bookshelf geometry, i.e. with smectic layers normal to the confining substrates. Furthermore, in order to keep the ECS layer and its operation intact, the material of ECS layer must be insoluble in the liquid crystal bulk material.

Although nematic liquid crystal devices exhibiting fast switching of the liquid crystal bulk molecules in response to an applied external field (switching to field-induced orientation state), and thus a short rise time of about 10 ms or less, have been provided, the obtainable decay time is still rather long, about 20-100 ms. The decay time is the time period needed for the liquid crystal bulk molecules to relax to their initial orientation when the electric field is removed (relaxation to field-off orientation state).

Fig 1 schematically shows a liquid crystal device 1 including a liquid crystal bulk layer 2 having a negative dielectric anisotropy ($\Delta\varepsilon < 0$) between confining sub-

strates 3. In the field-off state (E = 0), the liquid crystal bulk molecules are vertically aligned, via elastic forces, by a surface-director alignment layer (not shown) applied on the confining substrate surfaces 3. When an external electric field is applied (E ≠ 0) across the liquid crystal bulk layer 2 between electrodes 4 on the confining substrates 3, the liquid crystal molecules 2 are switched to a field-induced planar orientation. However, the liquid crystal molecules 2 located near the confining substrate surfaces 3 are not only affected by the applied electric field, but also by the surface-director alignment layer, which result in an elastic deformation D1 of the liquid crystal layer 2 near the substrate surfaces 3, as shown in Fig 1. After removal of the external field, the liquid crystal molecules 2 near the surface-director alignment layer relax to their initial field-off orientation, due to the solid surface/liquid crystal interactions. The relaxation of the liquid crystal molecules 2 in this region affects, via elastic forces, the orientation of the more remote liquid crystal bulk molecules 2. Thus, the elastic deformation D1 that takes place in the liquid crystal layer 2 under an applied electric field disappears and the initial uniform field-off homeotropic alignment of the entire liquid crystal bulk layer 2 is finally restored. However, as mentioned above, the relaxation to field-off orientation is rather slow. The rather long decay time results in a low image quality, in particular for moving images. This problem is especially pronounced for liquid crystal devices having large image displays.

The same type of problem is illustrated for the liquid crystal device 1′ shown in Fig 2, said device 1′ including a liquid crystal bulk layer 2′ having a positive dielectric anisotropy ($\Delta\varepsilon > 0$) between confining substrates 3′. In the field-off state (E = 0), the liquid crystal bulk molecules 2′ exhibit a planar alignment. When an external electric field is applied (E ≠ 0) across

the bulk liquid crystal layer 2′ between electrodes 4′ on the confining substrates 3′, the liquid crystal molecules 2′ are switched to a field-induced vertical orientation. An elastic deformation D2 of the liquid crystal layer 2′ near the substrate surfaces 3′ is shown in Fig 2.

Summary of the invention

In light of the above-mentioned drawback of the known liquid crystal displays, a general object of the present invention is to provide an improved liquid crystal device, an improved method for manufacturing a liquid crystal device, and an improved method of controlling a liquid crystal device. The invention is not directed to displays only, but is useful in many other liquid crystal applications.

According to a first aspect of the invention, there is provided a liquid crystal device including a liquid crystal bulk layer presenting a surface director at a bulk surface thereof, and a surface-director alignment layer arranged to interact with the bulk layer at said bulk surface for obtaining a preferred orientation of the surface director of the bulk layer, wherein said surface-director alignment layer exhibit a (non-zero) dielectric anisotropy thus being directly controllable by an electric field, and the liquid crystal bulk layer and the surface-director alignment layer exhibit dielectric anisotropies ($\Delta\varepsilon$) of opposite signs.

The device according to the invention makes it possible to shorten the decay time to below 20 ms, such as about 4-6 ms, and thus provide an improved image quality, in particular for moving images and large display devices.

According to a second aspect of the invention, there is provided a method for manufacturing a liquid crystal device comprising the steps of coating at least one substrate surface with an organic, dielectrically anisotropic compound providing a surface-director alignment layer, and bringing the surface-director alignment layer

into contact with a liquid crystal bulk layer presenting a surface director at a bulk surface thereof, wherein said surface-director alignment layer is arranged to interact with the bulk layer at said bulk surface for obtaining a preferred orientation of the surface director of the bulk layer and has a dielectric anisotropy ($\Delta\varepsilon$) of opposite sign to the liquid crystal bulk layer.

According to a third aspect of the invention, there is provided a method of controlling a liquid crystal bulk layer comprising the step of aligning a liquid crystal bulk layer presenting a surface director at a bulk surface thereof by use of a surface-director alignment layer arranged to interact with the bulk layer at said bulk surface for obtaining a preferred orientation of the surface director of the bulk layer and having a dielectric anisotropy ($\Delta\varepsilon$) of opposite sign to the liquid crystal bulk layer.

Brief description of the drawings

Fig 1 shows a prior art liquid crystal device exhibiting an initial vertical alignment of the liquid crystal bulk layer.

Fig 2 shows a prior art liquid crystal device exhibiting an initial planar alignment of the liquid crystal bulk layer.

Fig 3 shows an embodiment of the liquid crystal device according to the invention exhibiting an initial vertical alignment of the liquid crystal bulk layer.

Fig 4 and 5 illustrate the difference between the devices shown in Fig 1 and Fig 3, respectively, with regard to elastic deformation.

Fig 6 shows an embodiment of the liquid crystal device according to the invention exhibiting an initial planar alignment of the liquid crystal bulk layer.

Fig 7 and 8 illustrate the difference between the devices shown in Fig 2 and Fig 6, respectively, with regard to elastic deformation.

Fig 9 shows the rise and decay times measured for a device according to the invention exhibiting an initial vertical alignment of the liquid crystal bulk layer.

Detailed description of the invention

The liquid crystal device according to the invention includes a liquid crystal bulk layer presenting a surface director at a bulk surface thereof, and a surface-director alignment layer arranged to interact with the bulk layer at said bulk surface for obtaining a preferred orientation, such as planar, substantially planar, vertical or substantially vertical, of the surface director of the bulk layer, wherein said surface alignment layer exhibits a dielectric anisotropy thus being directly controllable by an electric field, and the liquid crystal bulk layer and the surface alignment layer exhibit dielectric anisotropies ($\Delta\varepsilon$) of opposite signs.

The dielectric anisotropy ($\Delta\varepsilon$) of a material having an ordered structure, such as a crystalline or a liquid crystalline structure, is the difference between the dielectric constants measured in perpendicular and parallel direction, respectively, to the preferred molecular orientation in this material.

When an electric field is applied across a material exhibiting a positive dielectric anisotropy ($\Delta\varepsilon > 0$), the molecules (or functional groups of the molecules) will align (or substantially align) their long axis in the direction of the electric field.

When an electric field is applied across a material exhibiting a negative dielectric anisotropy ($\Delta\varepsilon < 0$), the molecules (or functional groups of the molecules) will align their long axis perpendicular (or substantially perpendicular) to the direction of the electric field.

The liquid crystal device preferably includes at least one confining substrate, such as two confining substrates, at said bulk surface(s).

The surface-director alignment layer is preferably applied on the inner surface(s) of said substrate(s) confining the liquid crystal bulk layer.

The preferred orientation of the surface director of the liquid crystal bulk layer is generally obtained by interaction with the surface-director alignment layer in the absence of an external field, such as an electric field.

The liquid crystal bulk layer comprises a liquid crystal material exhibiting a (non-zero) dielectric anisotropy and thus being directly controllable by an applied electric field.

The liquid crystal bulk layer of the device according to the invention is preferably a nematic liquid crystal. When an electric field is applied across the bulk layer, the liquid crystal bulk molecules are switched out-of-plane.

The liquid crystal bulk layer may comprise a nematic liquid crystal material having a uniform or deformed configuration. The uniform configuration could, for instance, be planar, homeotropic or tilted. The deformed structure could, for instance, be twisted (i.e. cholesteric) or with splay and/or bent elastic deformation.

The nematic liquid crystals of the bulk layer may be achiral or chiral.

Examples of suitable liquid crystal bulk layer materials having positive and negative dielectric anisotropies, respectively, are give in relation to the preferred embodiments described below.

The material of the surface-director alignment layer may either present liquid crystal properties or it may not present liquid crystal properties.

Preferably, the material of the surface-director alignment layer is a liquid crystal material, such as a nematic or smectic liquid crystal material.

The material of the surface-director alignment layer may, for instance, be a polymeric material, such as a

chemically modified polyvinylalcohol, polyimide, polysiloxane, polyacrylate, polymethacrylate, polyamide, polyester, polyurethane, etc.

The surface-director alignment layer may also comprise a modified solid material, such as a chemically modified gold surface, a chemically modified silicon dioxide surface or a chemically modified glass surface comprising silanol groups.

The surface-director alignment layer may be produced by first applying a coating of a polymer having reactive groups on a substrate surface, and thereafter chemically attaching desired functional groups to said polymer coating by reaction with the reactive groups of the polymer, thus providing a desired surface-director alignment layer.

The surface-director alignment layer may also be produced by applying a coating of an already modified polymer on a substrate surface.

An alternative is to chemically attach desired functional groups to a non-polymeric substrate surface, such as a gold-coated substrate surface.

Examples of suitable-director surface alignment layer materials having positive and negative dielectric anisotropies, respectively, are give in relation to the preferred embodiments described below.

Fig 3 shows an embodiment of a liquid crystal device 5 according to the invention, wherein surface-director alignment layers 6 are applied on the inner surfaces of substrates 7 confining a liquid crystal bulk layer 8. The liquid crystal bulk 8 exhibits a negative dielectric anisotropy ($\Delta\varepsilon < 0$) and the surface-director alignment layers 6 exhibit a positive dielectric anisotropy ($\Delta\varepsilon > 0$).

The molecules (or the functional groups of the molecules) of the surface-director alignment layers 6 have in this embodiment an initial vertical orientation in relation to the confining substrate surfaces 7, thus resulting in vertically or substantially vertically aligned

liquid crystal bulk molecules 8 in the field-off state (E = 0). The surface-director alignment layers 6 are also preferably unidirectionally rubbed to obtain a preferred orientation of a field-induced planar alignment.

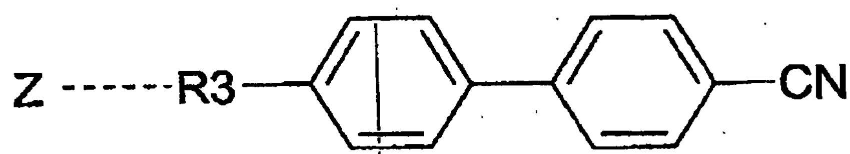
It shall be noted that even though the device 5 shown in Fig 3 comprises two surface-director alignment layers 6 (two-sided embodiment), the device according to the invention may alternatively comprise, for instance, only one surface-director alignment layer (one-sided embodiment).

When an external electric field is applied ($E \neq 0$) normally to the liquid crystal bulk layer 8 between electrodes 9 on the confining substrates 7, the liquid crystal bulk molecules 8 aligned vertically or substantially vertically will, due to their negative dielectric anisotropy, switch out-of-plane to a field-induced planar orientation. The molecules (or functional groups of the molecules) of the surface-director alignment layers 6 will, however, keep their initial vertical orientation which will be enhanced and stabilized by their positive dielectric anisotropy. In other words, the molecules (or the functional groups of the molecules) of the surface-director alignment layers 6 will not switch when an electric field is applied across the layers, thus causing a strong elastic deformation D2 of the liquid crystal layer near the substrate surface 7. When the external field is removed (E = 0), the vertically oriented molecules (or functional groups of the molecules) of the surface-director alignment layers will promote a fast relaxation from the field-induced planar orientation of the liquid crystal bulk molecules 8 back to their field-off vertical orientation. Thus, the elastic deformation D3 shown in Fig 3 is stronger than the elastic deformation D1 shown in Fig 1, and therefore the relaxation to the field-off orientation will in this case be faster than in the case shown in Fig 1. The comparison of D1 and D3, respec-

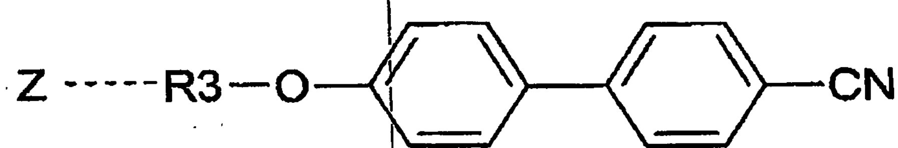
tively, is also schematically shown in Fig 4 and Fig 5, respectively.

The liquid crystal bulk layer 8 may have a negative dielectric anisotropy within the range of from -6 to -1, and the surface-director alignment layer(s) 6 may have a positive dielectric anisotropy within the range of from 1 to 30.

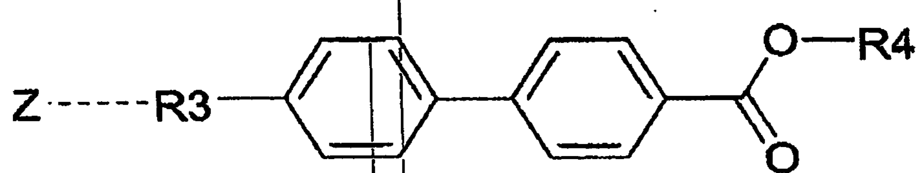
Examples of suitable surface-director alignment layer materials having a positive dielectric anisotropy are modified polymers having functional groups selected among the structures of Formulas I to V chemically bonded to the polymer main chain (Z):



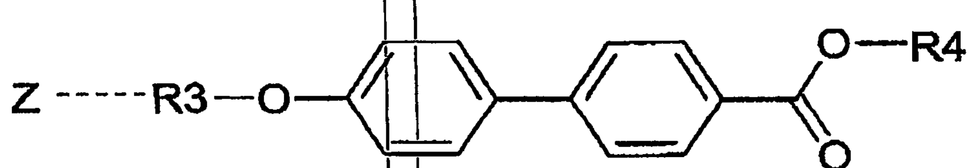
Formula I



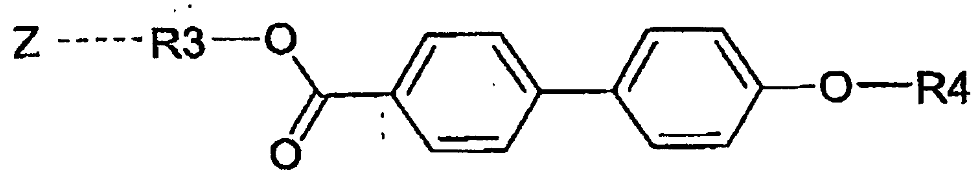
Formula II



Formula III



Formula IV



Formula V

wherein

R3 is a hydrocarbon chain comprising 4 to 20 carbon atoms (it shall be noted that the number of carbon atoms may vary along the polymer main chain),

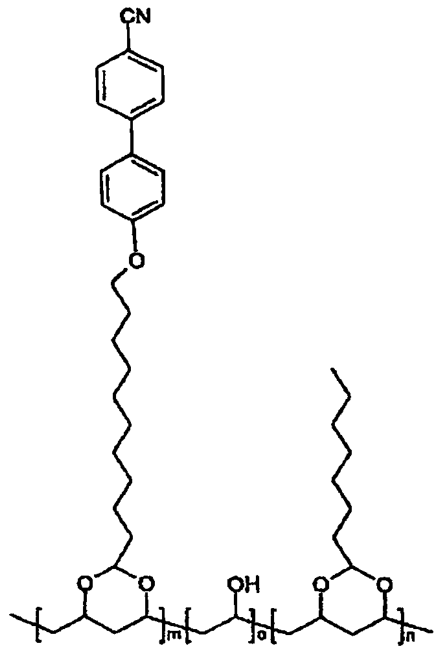
R4 is an alkyl group having 1 to 5 carbon atoms, and

Z is part of a polymer main chain.

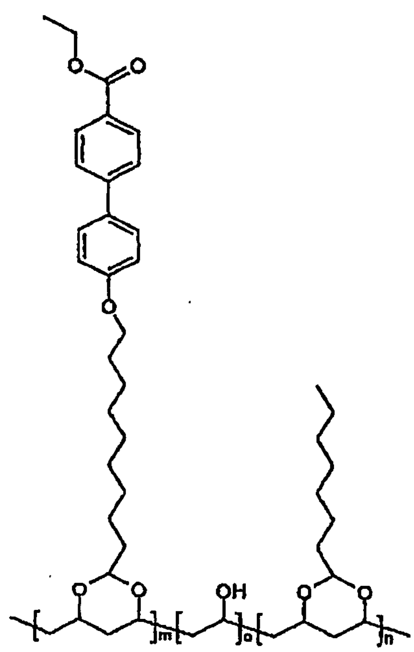
Instead of using a polymer, the functional groups of formula I to V can be chemically attached, as known to persons skiled in the art, to a solid surface, such as a gold surface, a silicon dioxide surface or a glass surface comprising silanol groups, to form a suitable material for use as the surface-director alignment layer acording to the invention.

Said functional groups of the surface-director alignment layer having a positive dielectric anisotropy are preferably mesogenic groups. It is believed that it, in some cases, might be advantageous if said mesogenic groups is capable of forming a smectic liquid crystalline phase.

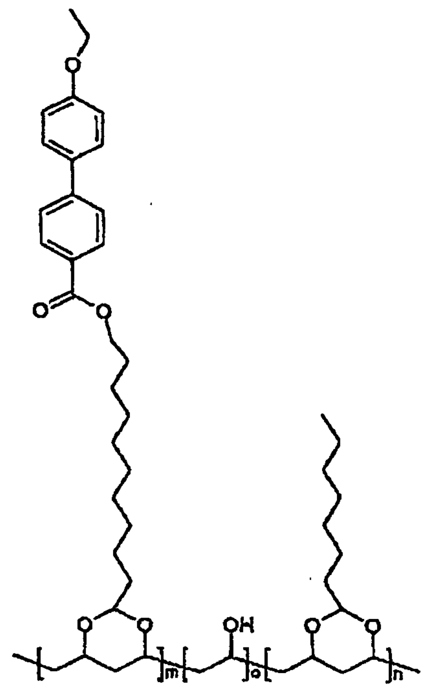
Specific examples of a suitable surface-director alignment material having a positive dielectric anisotropy are represented by Formulas VI to VIII:



Formula VI



Formula VII



Formula VIII

wherein (m+n)/o is within the range of from 25/50 to 43/14, preferably above 40/20, such as 42/16, and m/n is within the range of from 9/1 to 1/9, preferably 3/1 to 1/3, such as 2/1.

It shall be noted that in an embodiment of the invention comprising two surface-director alignment layers applied on substrate surfaces confining the liquid crystl bulk layer, the dipole moments of the functional groups of each surface-director alignment layer may either have the same direction or opposite directions.

A device having two separate alignment layers exhibiting the same directions of dipole moments is exemplified by a device having two separate alignment layers of the material according to Formula VI (or Formula VII).

A device having two separate alignment layers exhibiting the opposite directions of dipole moments is exemplified by a device having one alignment layer of the

material according to Formula VI (or Formula VII) and one alignment layer of the material according to Formula VIII.

Examples of suitable liquid crystal bulk layer materials having a negative dielectric anisotropy are a mixture of MLC 6608 ($\Delta\varepsilon$ = about -4) and MBBA ($\Delta\varepsilon$ = -0.8), a mixture of MLC 6684 ($\Delta\varepsilon$ = about -4 to -5) and MBBA ($\Delta\varepsilon$ = -0.8), and a mixture of MDA 98-3099 ($\Delta\varepsilon$ = -6) and MBBA ($\Delta\varepsilon$ = -0.8), all of which are nematic liquid crystal materials supplied by Merck.

Fig 6 shows another embodiment of a liquid crystal device 10 according to the invention, wherein surface-director alignment layers 11 are applied on the inner surfaces of substrates 12 confining a liquid crystal bulk layer 13. The liquid crystal bulk 13 exhibits a positive dielectric anisotropy ($\Delta\varepsilon > 0$) and the surface-director alignment layers 11 exhibit a negative dielectric anisotropy ($\Delta\varepsilon < 0$).

The molecules (or the functional groups of the molecules) of the surface-director alignment layers 11 have in this embodiment an initial planar orientation in relation to the confining substrate surfaces 12, thus resulting in planar or substantially planar aligned liquid crystal bulk molecules 13 in the field-off state ($E = 0$). The surface-director alignment layers 11 is also preferably unidirectionally rubbed to obtain a preferred orientation of the planar alignment (in field-off state).

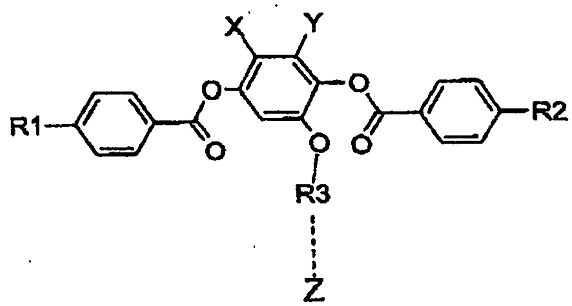
It shall be noted that even though the device 10 shown in Fig 6 comprises two surface-director alignment layers 11 (two-sided embodiment), the device according to the invention may alternatively comprise, for instance, only one surface-director alignment layer (one-sided embodiment).

When an external electric field ($E \neq 0$) is applied normally to the liquid crystal bulk layer 13 between electrodes 14 on the confining substrates 12, the liquid crystal bulk molecules 13 aligned planar or substantially

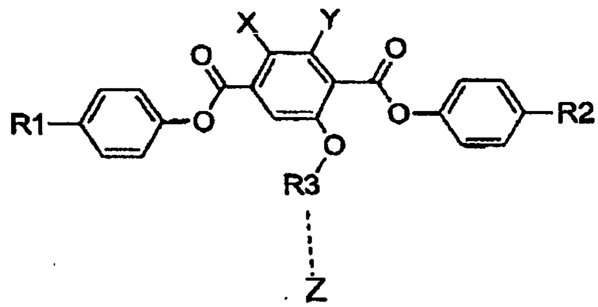
planar will, due to their positive dielectric anisotropy, switch out-of-plane to a field-induced vertical orientation. The molecules (or the functional groups of the molecules) of the surface-director alignment layers 11 will, however, keep their initial uniform planar orientation which will be enhanced and stabilized by their negative dielectric anisotropy. In other words, the molecules (or the functional groups of the molecules) of the surface-director alignment layers 11 will not switch when an electric field is applied across the layers 11. When the external field is removed (E = 0), the planar oriented molecules (or the functional groups of the molecules) of the surface-director alignment layers 11 will promote a fast relaxation from the field-induced vertical orientation of the liquid crystal bulk molecules 13 back to their initial field-off planar orientation. Thus, the elastic deformation D4 shown in Fig 6 is stronger than the elastic deformation D2 shown in Fig 2. The comparison of D2 and D4 respectively, is also schematically shown in Fig 7 and Fig 8, respectively.

The liquid crystal bulk layer 13 may have a positive dielectric anisotropy within the range of from 1 to 30, and the surface alignment layer(s) 11 may have a negative dielectric anisotropy within the range of from -6 to -1.

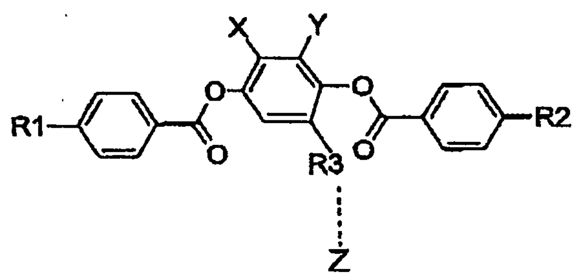
Examples of suitable surface-director alignment materials having a negative dielectric anisotropy are modified polymers having functional groups selected among the structures of Formulas IX to XV chemically bonded to the polymer main chain (Z):



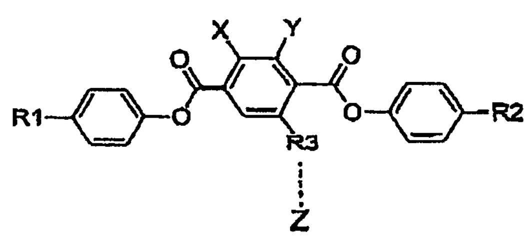
Formula IX



Formula X



Formula XI



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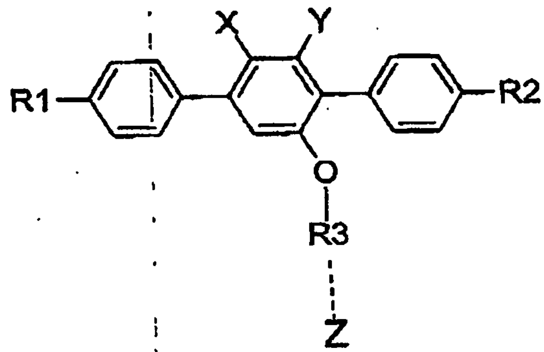
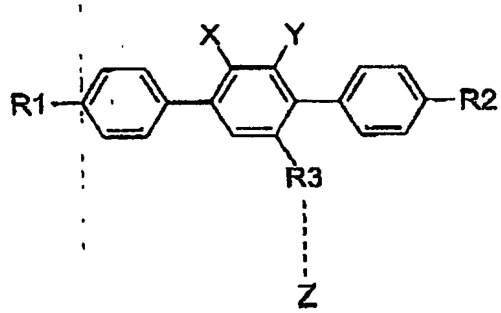
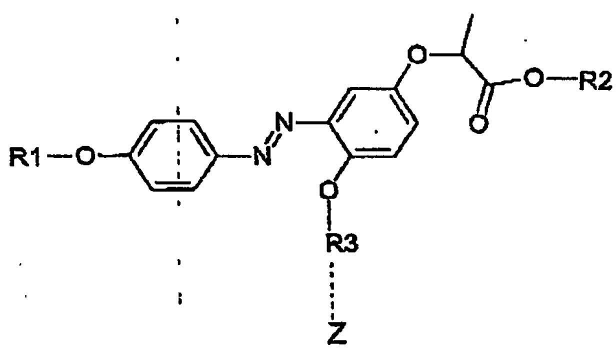


Formula XIII



Formula XIV



Formula XV

wherein

X and Y each independently are H, F, Cl, CN, or CF_3,

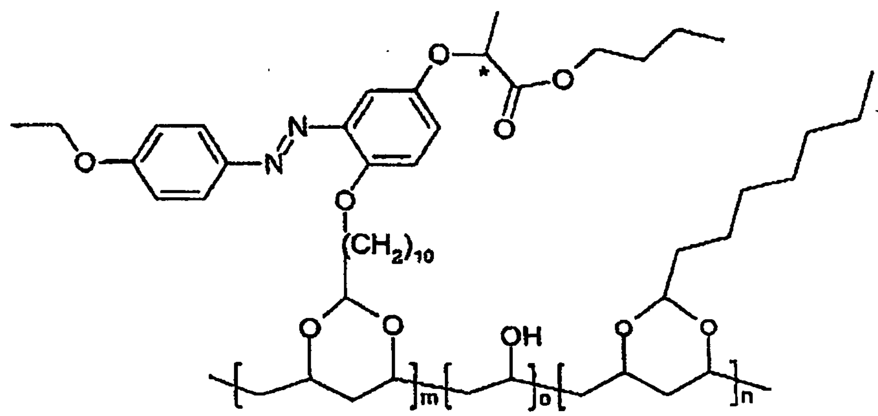
R1 and R2 each independently are an alkyl or an alkoxy group comprising 2 to 12 carbon atoms,

R3 is a hydrocarbon chain comprising 4 to 20 carbon atoms (it shall be noted that the number of carbon atoms may vary along the polymer main chain),

Z is part of a polymer main chain.

Instead of using a polymer, the functional groups of formula IX to XV can be chemically attached, as known to persons skiled in the art, to a solid surface, such as a gold surface, a silicon dioxide surface or a glass surface comprising silanol groups, to form a suitable material for use as the surface-director alignment layer acording to the invention.

Specific examples of a suitable surface-director alignment materials having a negative dielectric anisotropy are represented by Formula XVI:



Formula XVI

wherein (m+n)/o is within the range of from 25/50 to 43/14, preferably above 40/20, such as 43/18, and m/n is within the range of from 9/1 to 1/9, preferably 3/1 to 1/3, such as 1/1.

Examples of suitable liquid crystal bulk layer materials having a positive dielectric anisotropy are E44 ($\Delta\varepsilon = +16.8$), E9, and E70 A ($\Delta\varepsilon = +10.8$), all of which are nematic liquid crystal materials supplied by Merck.

Examples

A liquid crystal display glass substrate having a thickness of 1.10 mm was used. One side of the substrate had an ITO (indium tin oxide) layer (electrode material) with a surface resistance of 80 Ω/cm^2. The glass was cut into pieces with a size of 9,5 X 12,5 mm, and the edges were grinded.

The substrates were then washed several times in distilled water in an ultra-sonic bath, dried and then washed two times in isopropanol. The substrates were thereafter moved into a clean-room.

The ITO side of the substrates was spin coated with a surface-director alignment layer material, dissolved in THF to a concentration of about 0.1-0.5%. The speed was 3000-4000 rpm and coating was performed during 30 seconds.

After coating, the substrates were heated for approximately 5-10 minutes at a temperature of 125°C. Then the substrates were set to cool.

The applied surface-director alignment layer, on top of the ITO layer, was buffed with a velvet cloth. All substrates were buffed in the same direction. When the cell was put together, one substrate was rotated 180°, thus making the buffing direction parallel in the cell.

Two substrates were put together to a cell using UV-glue (Norland NOA68), and spacers at two edges. The cell was then put under pressure in a UV-exposure box for 15 minutes.

Small electric cords were ultra-sonically soldered to each ITO-surface of the cell.

A nematic bulk liquid crystal material was introduced into the cell in isotropic phase by means of capillary forces.

Example 1: *Electrically stabilised vertical alignment*

The ITO side of the substrates was coated, as described above, with a polymer material according to Formula VI wherein (m+n)/o is 42/16 and m/n is 2/1. It

shall be noted, however, that any one of the structures according to Formula I to VIII may be used in this embodiment.

The polymer layer (about 100 nm) was rubbed unidirectionally very lightly to induced a small pretilt of the side mesogenic groups of the polymer, and the cell was thereafter assembled.

The sandwich cell (cell gap about 3 μm) was then filled with the nematic mixture MBBA/MLC6608 (Merck, Germany), 60/40 wt%, exhibiting $\Delta\varepsilon < 0$.

In this cell, the polymer layer acts as a surface-director alignment layer.

The alignment of the cell after cooling to room temperature was inspected by means of a polarising microscope and it was found to be uniform vertical.

The response rise and decay times were measured in a set-up comprising a polarising microscope, a photo-detector, an oscilloscope and a puls generator.

The electro-optic response of the cell with vertical alignment, under application of unipolar impulses with low frequency (about 1 Hz), is depicted in Fig 9. At a voltage (U) of 9.2 V, the measured rise and decay time are about 2 and 4 ms, respectively. Thus, the measured decay time is about 5-10 times shorter than the decay time usually measured in liquid crystal cells with vertical alignment.

<u>Example 2:</u> *Electrically stabilised planar alignment*

The ITO side of the substrates was coated, as described above, with a polymer material according to Formula XVI wherein (m+n)/o is 43/18 and m/n is 1. It shall be noted, however, that any one of the structures according to Formula IX to XVI may be used in this embodiment.

The polymer layer (about 100 nm) was rubbed unidirectionally to ensure uniform planar alignment of the side mesogenic groups of the polymer, and the cell was thereafter assembled.

The sandwich cell (cell gap about 3 µm) was then filled with the nematic mixture E7 (BDH, UK) exhibiting $\Delta\varepsilon > 0$.

In this cell, the polymer layer acts as a surface-director alignment layer.

The alignment of the cell after cooling to the room temperature was inspected by means of a polarising microscope and it was found to be uniform planar.

The response rise and decay times were measured in a set-up comprising a polarising microscope, a photo-detector, an oscilloscope and a puls generator.

The electro-optic response of the cell with planar alignment, under application of unipolar impulses with low frequency (about 1 Hz), was found to be about 0.5 ms and 4 ms for rise and decay times, respectively.

CLAIMS

1. A liquid crystal device including a liquid crystal bulk layer presenting a surface director at a bulk surface thereof, and a surface-director alignment layer arranged to interact with the bulk layer at said bulk surface for obtaining a preferred orientation of the surface director of the bulk layer, characterised in that the liquid crystal bulk layer and the surface-director alignment layer exhibit dielectric anisotropies ($\Delta\varepsilon$) of opposite signs.

2. A liquid crystal device according to claim 1, wherein the liquid crystal bulk layer comprises a nematic liquid crystal.

3. A liquid crystal device according to claim 1 or claim 2, wherein the liquid crystal bulk layer has a negative dielectric anisotropy ($\Delta\varepsilon$) and the surface-director alignment layer has a positive dielectric anisotropy ($\Delta\varepsilon$).

4. A liquid crystal device according to claim 1 or claim 2, wherein the liquid crystal bulk layer has a positive dielectric anisotropy ($\Delta\varepsilon$) and the surface-director alignment layer has a negative dielectric anisotropy ($\Delta\varepsilon$).

5. A method for manufacturing a liquid crystal device characterised in comprising the steps of:

coating at least one substrate surface with an organic, dielectrically anisotropic compound providing a surface-director alignment layer, and

bringing the surface-director alignment layer into contact with a liquid crystal bulk layer presenting a surface director at a bulk surface thereof, wherein said

surface-director alignment layer is arranged to interact with the bulk layer at said bulk surface for obtaining a preferred orientation of the surface director of the bulk layer, and has a dielectric anisotropy (Δε) of opposite sign to the dielectric anisotropy (Δε) of the liquid crystal bulk layer.

6. A method of controlling a liquid crystal bulk layer comprising the step of aligning a liquid crystal bulk layer presenting a surface director at a bulk surface thereof by use of a surface-director alignment layer arranged to interact with the bulk layer at said bulk surface for obtaining a preferred orientation of the surface director of the bulk layer c h a r a c t e r i s e d in that said surface-director alignment layer has a dielectric anisotropy (Δε) of opposite sign to the dielectric anisotropy (Δε) of the liquid crystal bulk layer.

Abstract

The invention relates to a liquid crystal device including a liquid crystal bulk layer and an electrically stabilized surface alignment layer, said layers exhibiting dielectric anisotropies ($\Delta\varepsilon$) of opposite signs.

The invention also relates to a method for manufacturing a liquid crystal device and a method of controlling a liquid crystal bulk layer.

Figure elected for publication: Fig 3

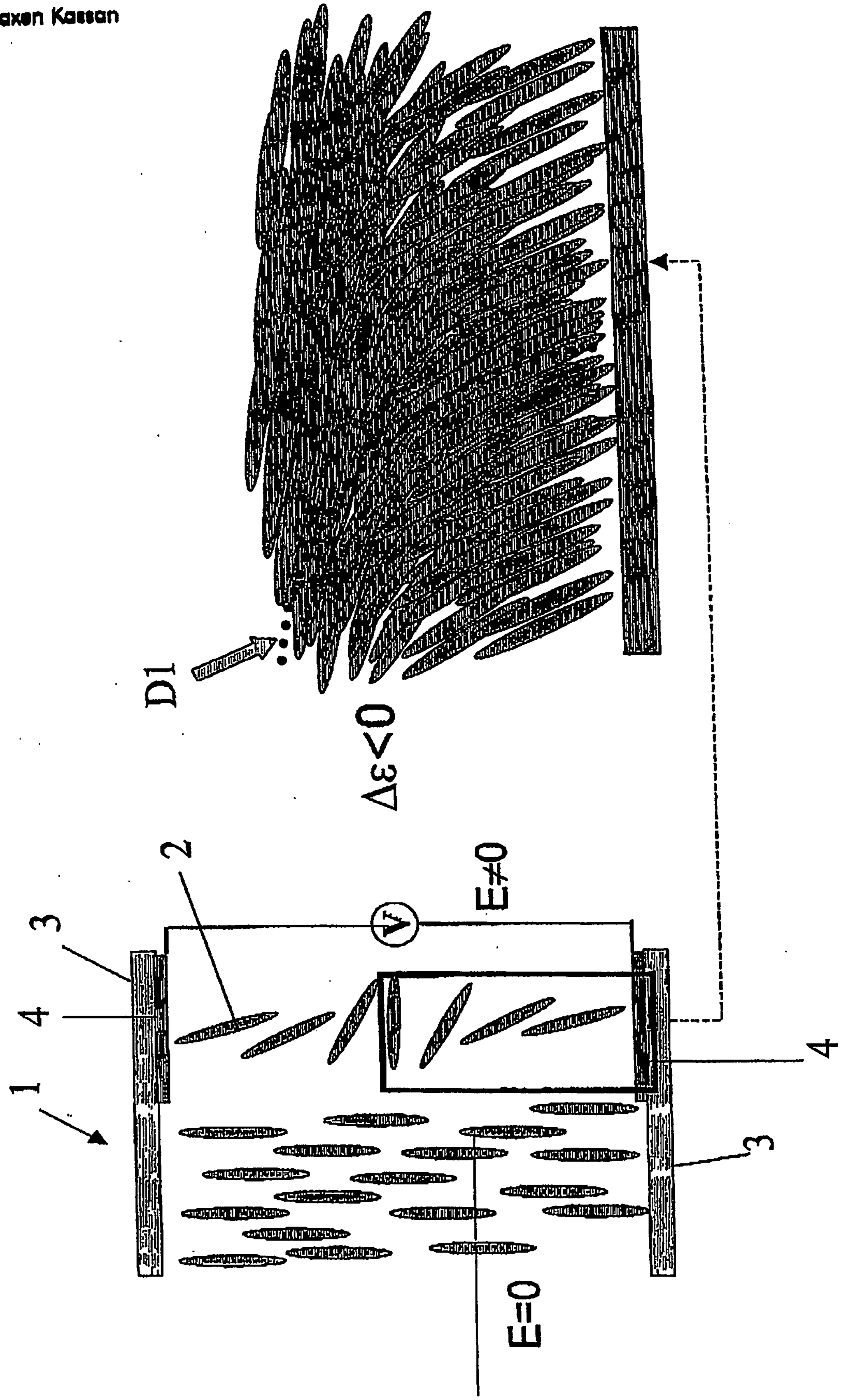


Figure 1

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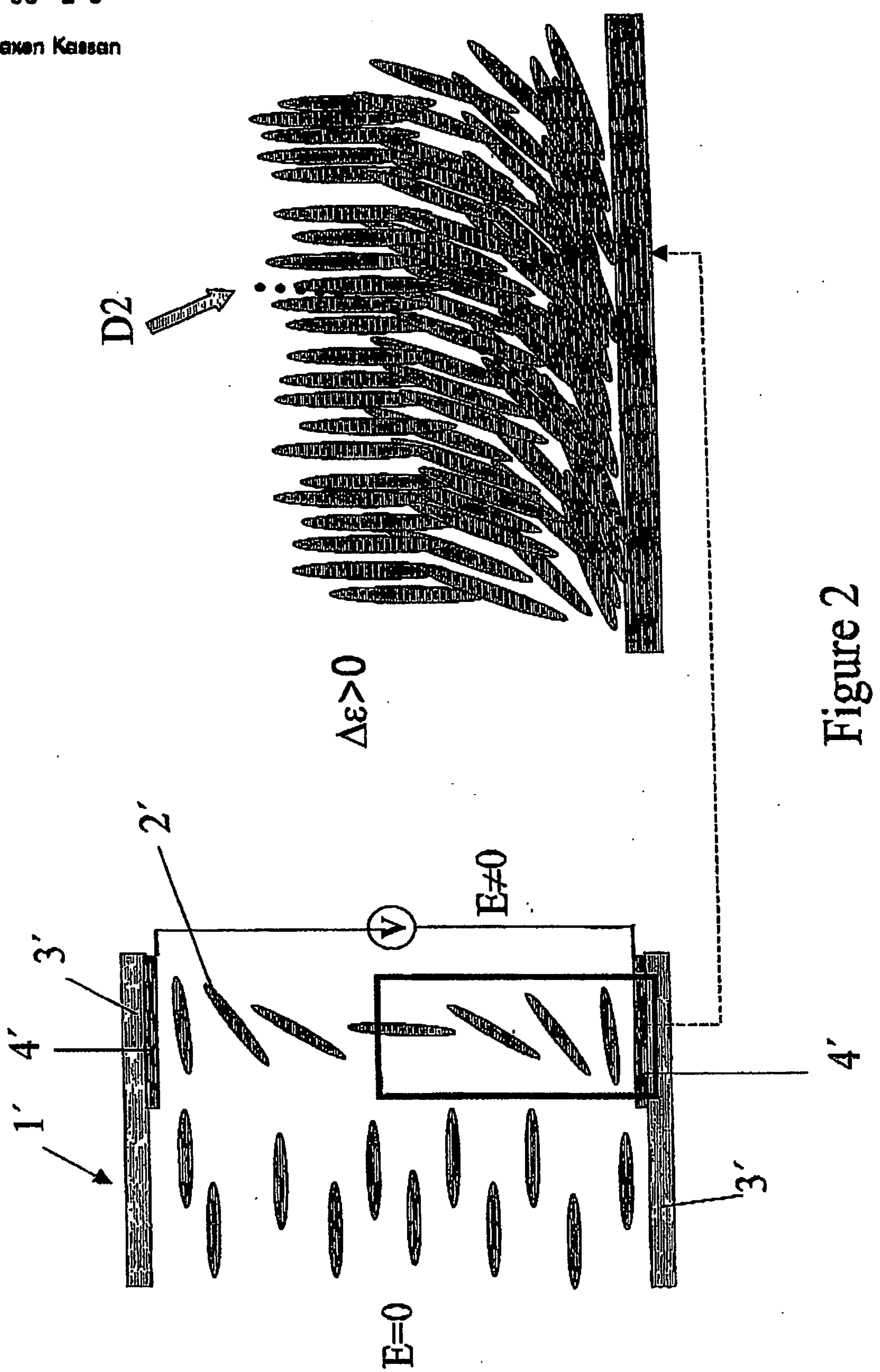

Figure 2

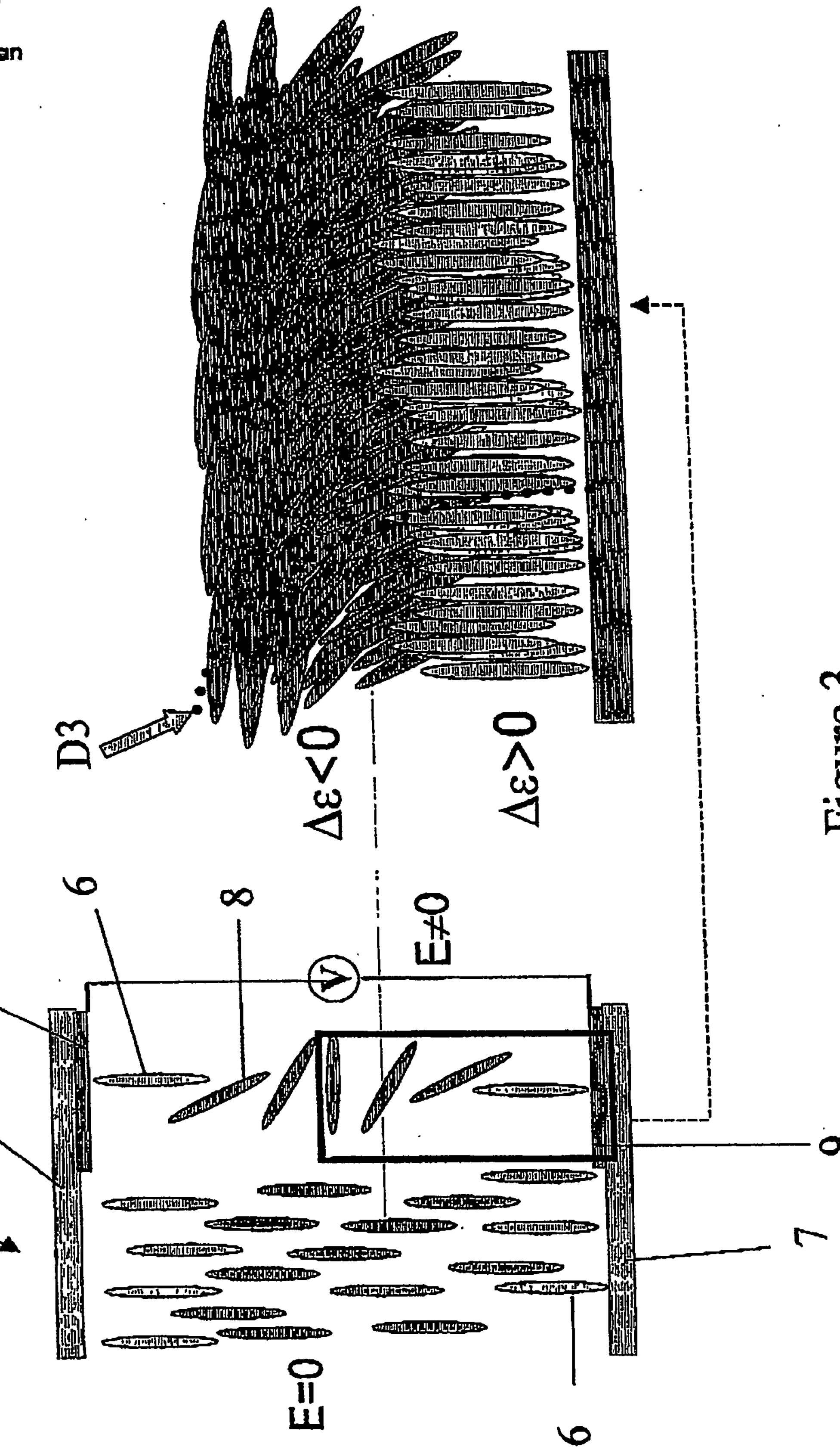

Figure 3

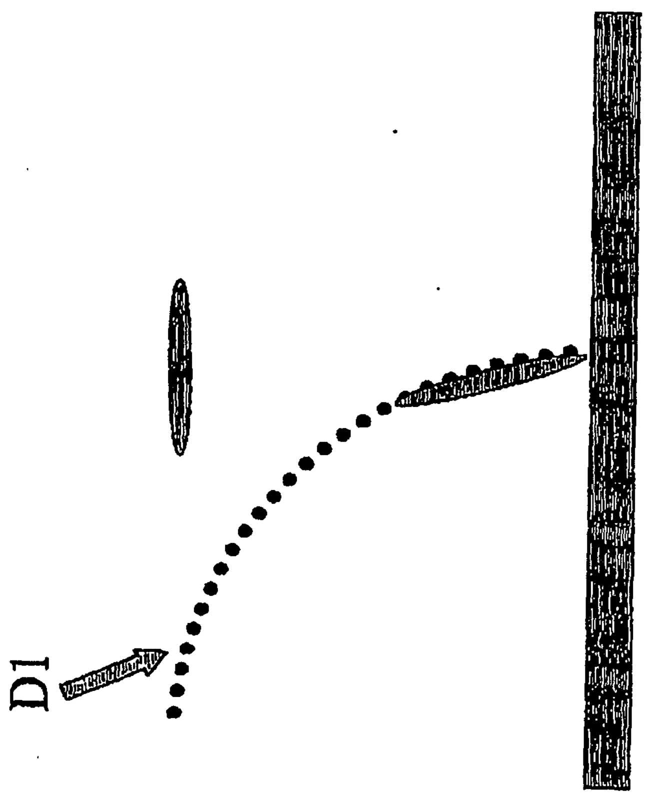

Figure 4

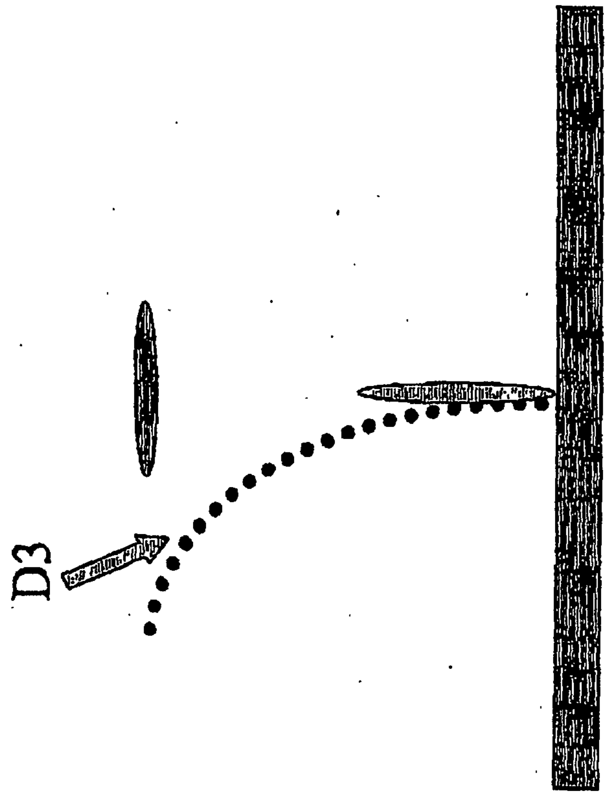

Figure 5

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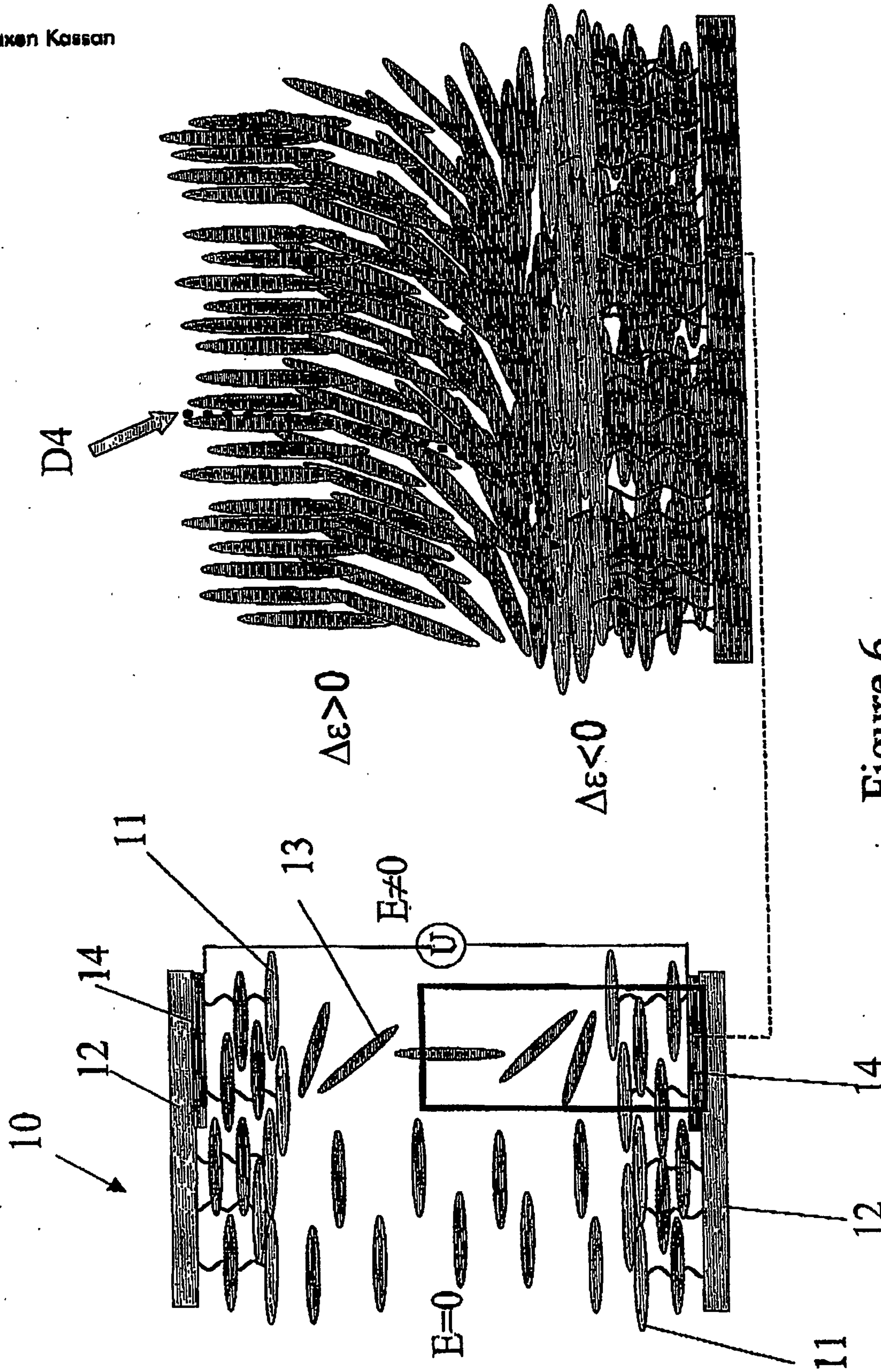

Figure 6

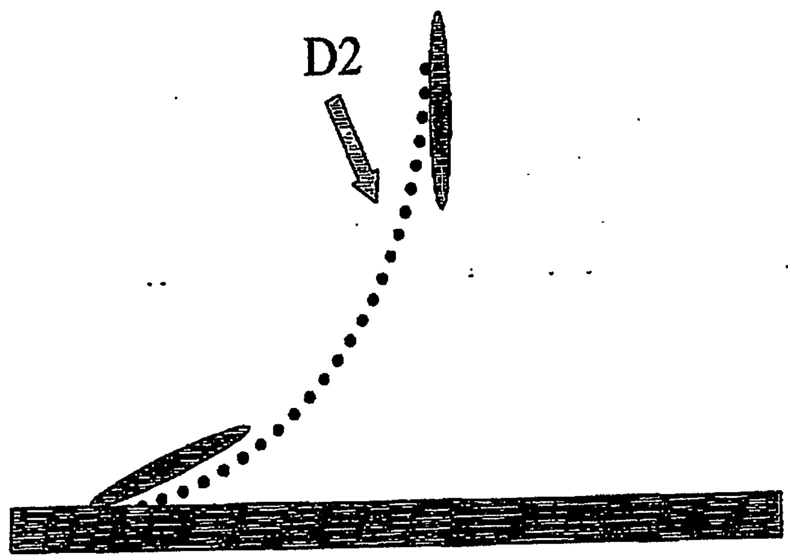

Figure 7

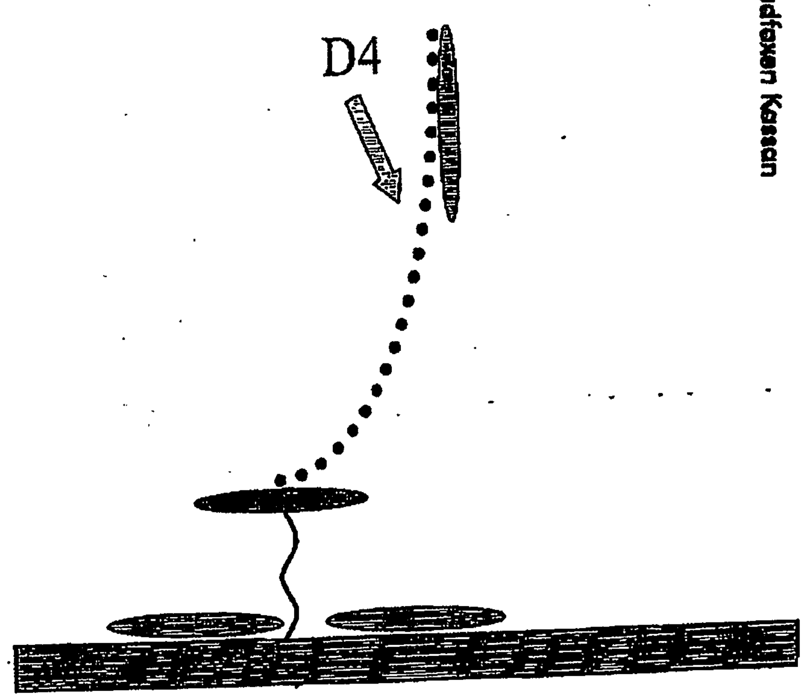

Figure 8

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Huvudfaxen Kassan

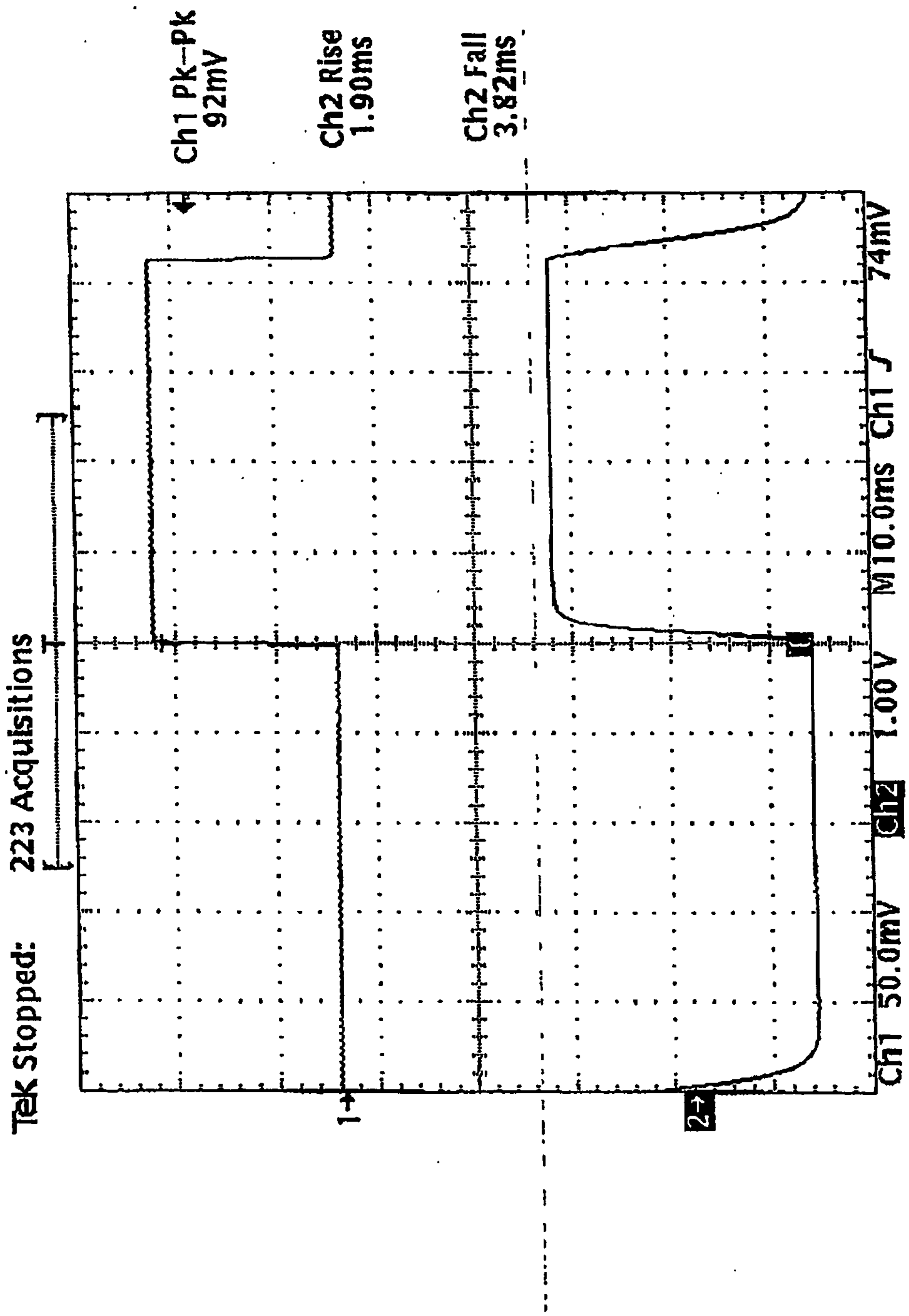

Figure 9